Home Intercommunication System using Visible Light Communications

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Abstract: The fast growing technology of wireless data transmission through the illumination of light emitting diodes (LEDs) is known as visible light communications (VLC). This technology makes use of visible light as the carrier for transmitting signals over a wireless channel. VLC uses the visible light spectrum for transmission and one of the main advantages of VLC over radio frequency (RF) based communications is that VLC is not susceptible to electromagnetic interference. In this project, VLC is used for the transmission of audio over an optical wireless channel. This is achieved by designing and implementing a simplex intercom system that comprises of a transmitter, a channel and a receiver and the system transmits audio through visible light using on-off keying (OOK) modulation. In this modulation scheme, the intensity of light is varied by switching the LED on and off at a high frequency such that the switching is not detectable by the human eye. The results of the project demonstrate that audio transmission is achievable with visible light.

Keywords: Intercommunication system, VLC, OOK modulation, Light Emitting Diode, radio waves, Light-Fidelity (Li-Fi), Wireless-Fidelity (Wi-Fi).

1 1. Introduction

Visible light communications (VLC) is an optical wireless technology that uses the illumination of light to transmit data. It comprises of light emitting diodes (LED) whose current is intensified by modulation [1]. Unlike the commonly known transmission of signals through cables and wires, VLC uses a wireless channel composed only of visible light.

Visible light communications consist of a transmitting device, a channel and a receiving device. The transmitting device is responsible for modulating a signal in order to switch an LED on and off at high speeds. The channel is a wireless medium and the receiving device consists of a photo detector as a component which receives the transmitted signal.
The transmission of data using LEDs was introduced by the Nakagawa Laboratory in Keio University, Japan in 2003 [2] [3]. This opened a platform for the light-fidelity (Li-Fi) technology which uses light emitting diodes to transmit data wirelessly. Since then, there have been on-going research activities on VLC using LEDs. The choice of LEDs is based on the fact that they are often small in size, they have a longer lifetime and they have low energy consumption when compared to other incandescent lights [1] [4] [5]. Their main advantage is their fast switching characteristics since they can be switched on and off at operating speeds less than 1 μs [6]. These switching characteristics are the key in visible light communications because the current intensity of the LEDs needs to be modulated at speeds that cannot be detected by the human eye [6]. Since there are different modulation methods, the modulation technique implemented is based on the application of the system

designed. The various modulation techniques include colour shift keying (CSK), orthogonal frequency division multiplexing (OFDM), on-off keying (OOK) and pulse position modulation (PPM).
The advantages of VLC over Wireless-fidelity (Wi-Fi) technology are the main reasons why VLC is becoming more of a preferable choice in communications for certain applications. Radio frequencies (RF) have a limited spectrum with a frequency less than 300 GHz, and the growing demand of wireless communications has resulted in a congested, scarce and expensive radio frequency spectrum [1] [7] [8]. Electromagnetic Interference is potentially dangerous as it is known to interfere with airplane instruments and hospital equipment. Radio frequency based intercom systems are prone to electromagnetic interference when exposed to medical monitors and neonatal radiant heaters in hospitals [9] [10] [11]. This results in the malfunction of these devices and the reading of incorrect results. This is a serious problem which may even lead to fatality [11]. In addition to this, the transmission power of RF is limited to certain levels, once those levels are exceeded this becomes a serious health risk for humans [1].

Visible light on the other hand has a wide spectral range as it covers between 350 nm and 800 nm of wavelength, and its frequencies are comprised between 4.3×10^{14} Hz and 7.5×10^{14} Hz [2]. The application of VLC is not limited only to indoor use; it is also used outdoors in traffic lights and vehicle headlights for effective vehicle communication. It can be used in aircrafts and hospitals where Bluetooth, infrared and Wi-Fi are banned due to electromagnetic interference (EMI).

1. Objectives

Visible light communication is a technology which is implemented to solve issues regarding security, limited availability and inefficiency of radio waves.

The main objective of this project is to design an intercommunications system using visible light communications. For this reason, the system shall be designed to create a point-to-point line-of-sight transmission link.

VLC has multiple modulation methods that can be implemented in a communication system. Another objective is to investigate the OOK modulation scheme to be used in modulating the current intensity of the LED and then use the investigated information to design a VLC intercommunications system.

Since VLC uses LEDs which are already used in most of the lighting systems both indoor and outdoor [12], this implies that the cost of implementing VLC systems is reduced. This project shall be dedicated to design an intercom system to also be used in places where radio frequency based intercom systems pose as a risk to human health.

2. Methodology

The project shall consist of several phases which are correlated. Each phase needs to be completed before moving on to the next one in order to avoid the possibility of chaotic results. Going through the phases one step at a time is crucial.

Phase 1: Investigation
The first step to any project design is to investigate the project. In this phase, visible light communications will be investigated together with OOK modulation that will be

implemented to design an intercom system. Additionally, a comparison investigation shall be made between radio waves and VLC.

Phase 2: Designing
The intercom system is designed during this phase. The design process includes establishing parameters for the transmitter, channel and receiver according to requirements. The cost and quality of the apparatus to be used will also be considered.

Phase 3: Implementing
The chosen design shall be implemented to build the final communication system. This is the process of building the system using acquired building skills and knowledge.

Phase 4: Testing
This is a crucial phase as it determines the functionality and the reliability of the system. The VLC intercom shall be put to test to determine if the project objective was met or not. If errors occur during testing, the design phase needs to be reviewed and corrective measured shall be taken.

Phase 5: Project Execution
Once the project has passed the testing phase it shall be executed to demonstrate its operation as well as its effectiveness.

3. Technology Description

The block diagram below shows the details of the proposed design. Each block has its significance in the designing of the intercom system and the blocks will therefore be described below.

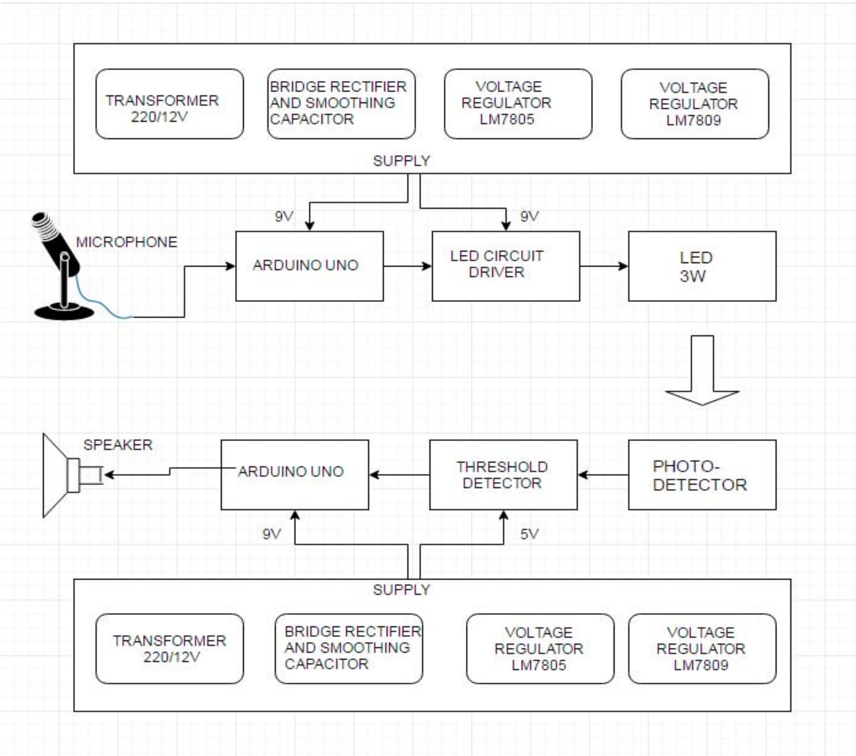

Figure 1: Proposed design block diagram

1.1 Supply

The supply consists of a transformer responsible for stepping down voltage from 220V AC to 12V AC. This AC voltage is then full wave rectified through a full bridge rectifier and the ripple voltage that results is eliminated through smoothing capacitors. The output voltage is then reduced to 9V, through a LM09 voltage regulator, in order to supply both the Arduino and the LED driver circuit in the transmitter. The supply in the receiver side shall work in the same way, but it will supply 9V DC to the Arduino and 5V DC to the phototransistor collector terminal.

1.2 Microphone

The type of microphone chosen is a condenser microphone. It shall receive an analog audio signal which is read as a voltage. This audio signal needs to be converted to a digital signal and this leads to the next block in the block diagram.

1.3 Arduino and LED driver

The arduino together with the LED driver form the OOK modulator. The Arduino will be responsible for generating a frequency of 7 kHz and converting the audio it received into bits of 1s and 0s. Thereafter the LED will be switched on when it received a binary bit 1 and will be switched off when it receives a binary bit 0. This switching will be done at the frequency of They will both be responsible for switching the LED on and off at very high kHz as generated by the arduino. At this frequency, the LED appears to be constantly on and the switching cannot be detected by the human eye. This forms the modulation part in the transmitter.

1.4 LED

The 3 Watt white LED is the output of the transmitter, and will be responsible for carrying the audio signal during illumination. It is therefore the carrier of the audio signal since it will be switching according to the data it receives.

1.5 Photodetector, Threshold detector and Arduino

The photodetector shall be a phototransistor and it will form part of the threshold detector which will be responsible for detecting the received signal. The received signal will be in the form of light which alternates between the on and off states as emitted by the LED. When the phototransistor detects light, it will generate a current that will flow through the receiver circuit. Upon receiving the light, this will assist in determining whether the received level represents an on or an off state. The arduino in the receiver side will then demodulate the signal. The signal will then be passed on to a digital to analog converter where the output will be a voltage signal.

1.6 Speaker

The speaker is the output of the receiver circuit and this is where the audio signal should be audible. The voltage signal will be received by the speaker and the audio signal will be played at the speaker. This is a 5 Ohm, 4 – 8 Watt speaker.

4. Developments

An arduino development board was used for OOK modulation. A code was developed which was responsible for switching the LED on and off according to the audio binary bit it received. A non-return-to-zero (NRZ) OOK format was used for this project. In the non-return-to-zero format, when there are successive 1s in a signal, the optical intensity does not return to 0 between the 1s. This implies that long strings of 1s and 0s occur with no transitions in-between the successive strings.

To ensure that the project functions properly, a functional experiment was conducted. The functional experiment tests the transmission distance at which the audio signal can be transmitted before it becomes distorted. Below is a figure of the experimental setup.

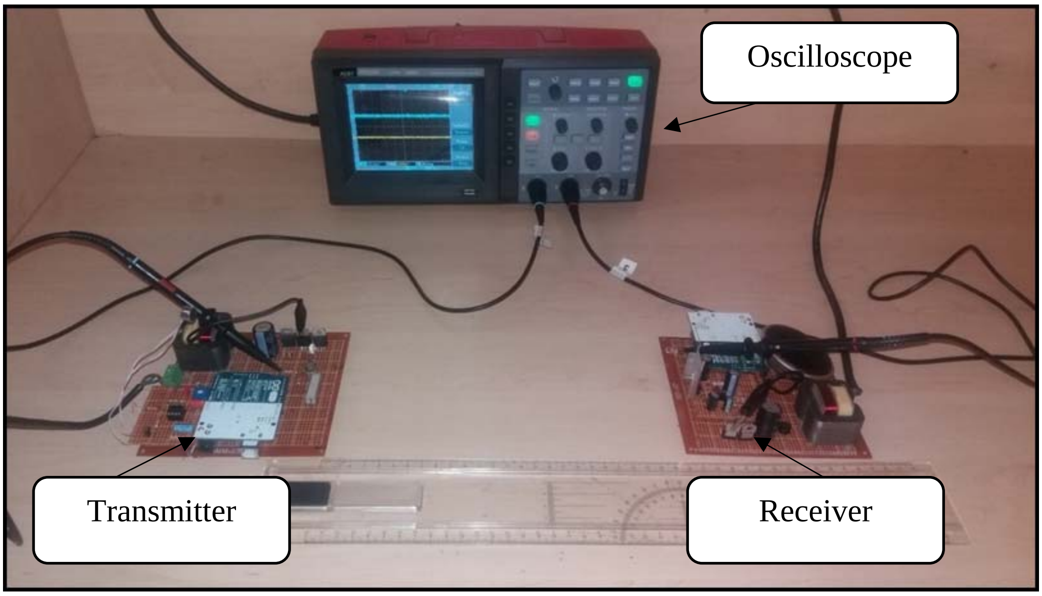

Figure 2: Distance test experimental setup

5. Results

The effect of the distance between the transmitter and receiver was determined. This was done by initially placing the receiver at a distance of 2cm from the transmitter and then increasing the distance while recording the results for every increase in distance. Below is the signal that was displayed on the oscilloscope when the transmitter was placed 2cm from the receiver, as well as when it was placed 20cm from the transmitter.

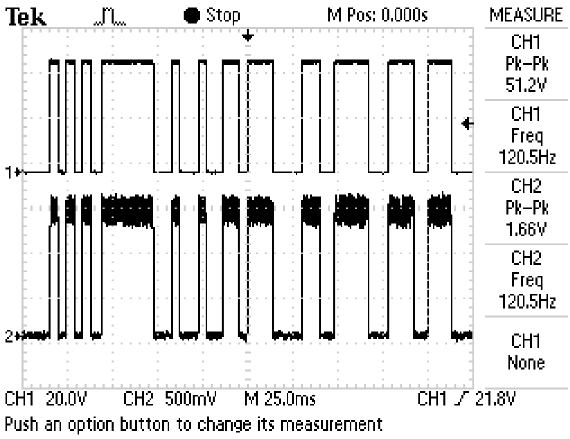

Figure 3: Modulated audio signal with receiver placed 2cm from the transmitter.

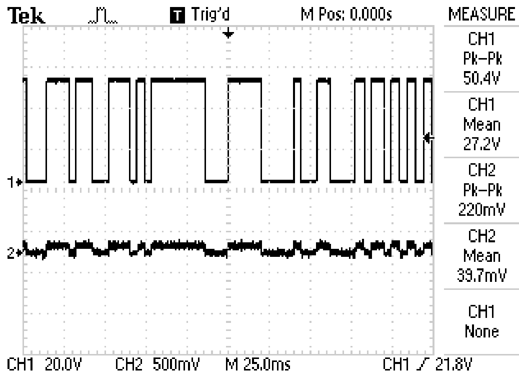

Figure 4: Modulated audio signal with receiver placed 30cm from the transmitter.

Figure 3 and 4 shows the difference in the received signal when the distance between the transmitter and receiver is increased. It can be seen in figure 3 that the received signal has a high amplitude which is almost identical to the transmitted signal. However, in figure 4 the received signal has a very low amplitude at 20cm. This is due to the fact that the further away the receiver is to the transmitter, the lower the brightness of the LED. This means that the phototransistor detects a light of less intensity and this results in a small current flowing through it. This relationship can be seen through the following set of results;

Table 1: Results of measured current as a function of distance.

Distance (cm)	**Current (μA)**
2	980
4	406
6	250
8	180
10	125
12	94
14	67
16	63
18	53
20	44
22	36
24	31
26	27
28	24
30	21

The plot below is a graphical representation of the relationship between the distance between the transmitter and receiver and the current detected by the phototransistor.

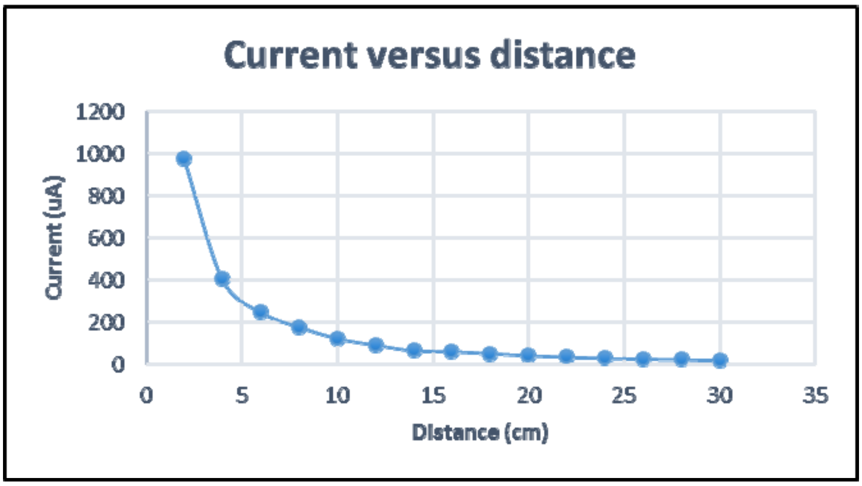

Figure 5: Current flowing through phototransistor versus distance.

In the plot above shown in figure 5, when the transmitter and receiver are close to each other, the light intensity received by the phototransistor is very strong. Hence, the current developed in the phototransistor is high (close to a 1000 micro Amps) and the measured peak to peak voltage was 1.66V. When the distance was increased to 4cm, the current dropped drastically to 406 micro Amps. A further increase in the distance results in a drastic drop of current developed in the photodetector. It was noted however, that at 14cm the decrease in current became gradual. These results are in line with what is expected since they correspond with the Inverse Square Law, where in this case, it shows that the current intensity is inversely proportional to the square of the distance from the source of light. The Inverse Square Law can be seen in figure 5.

6. Business Benefits

Wireless intercom systems provide an effective and simple way of communication in schools, airplanes the workplace, homes and hospitals. Current wireless intercom systems use Wi-Fi for audio transmission, which pose as a danger in places such as hospitals and airplanes. This is due to the fact that Wi-Fi is a technology that uses the radio wave spectrum to transmit data wirelessly. The radio waves are prone to electromagnetic interference and as a result they interfere with medical devices.

Introducing an intercom system that uses VLC solves this issue since visible light is not susceptible to electromagnetic interference. It is cost effective since it uses LEDs for illumination and all the components that were used to build the system are inexpensive. The system will also be beneficial in neonatal care units in hospitals and in rooms where there are medical monitors because the system does not interfere with the devices in such areas.

7. Conclusions

Wi-Fi uses the radio frequency spectrum which is congested and systems that use Wi-Fi can be potentially dangerous when they interfere with hospital and airplane equipment. This project demonstrates that audio transmission is achievable using visible light and it ensures cheap and effective communication.

Medical pagers are a very effective way of communication in hospitals and they still make use of radio waves. For future work, the system may be further improved to be used in hospitals together with medical pagers. The transmitter can be used to illuminate hospital rooms and the medical pages can be the receivers. Since it has been shown through this project that audio can be transmitted through visible light. The application can be further extended to be used as portable devices with the use of more efficient and space saving components.

8. References

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